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(54) Title: FUSION PROTEINS AS IMMUNIZATION TREATMENTS OF ALZHEIMER'S DISEASE

(57) Abstract: The present invention is related to fusion proteins (Aβ-Hsp) (III) and their use in the treatment or prophylaxis of disorders associated with an accumulation of β-amyloid, specificallyin patients with Alzheimer's disease. Said fusion proteins (III) are derived from the condensation of β-amyloid protein or fr agments thereof (Aβ) (I) with a heat shock protein (Hsp) (II) according to the following pathway: (Formula).

FUSION PROTEINS AS IMMUNIZATION TREATMENTS OF ALZHEIMER'S DISEASE

The present invention is related to fusion proteins derived from the condensation of β-amyloid protein or a fragment thereof and a heat shock protein, to the pharmaceutical preparations that contain them and to their use in the treatment or prophylaxis of disorders associated with the overproduction of β-amyloid, specifically, in patients with Alzheimer's disease.

BACKGROUND

Alzheimer's disease is a growing problem in developed countries. This disorder accounts for approximately 170,000 deaths in the United States every year, placing it in third place (7.1% of total deaths) as cause of death (Ewbank DC, *Am J Public Health* 1999; 89: 90-92). The yearly cost of Alzheimer's disease in the United States is estimated to be 100 billion dollars (Schumock GT, *Am J Health Syst Pharm* 1998; 55, Suppl. 2, : S17-S21). The cost of treating each patient is estimated to be 195,000 dollars, with a significant amount of this cost being attributed to the loss of productivity of the patient and caregiver and to costs sustained by the family. The average annual cost for the care of patients with a mild, moderate or severe form of the disorder, is approximately 19,000, 31,000 and 37,000 dollars, respectively. The availability of drugs capable of slowing the development of the disease would lead to an estimated yearly savings of approximately 25,000 dollars per patient in medical assistance costs alone (Leon J *et al*, *Health Aff* 1998; 17: 206-216).

From an anatomic point of view, Alzheimer's disease is characterized by an atrophy of the cerebral cortex and by a massive loss of cortical neurons and cholinergic projections made by the nucleus basalis towards the cortex.

From a histopathologic point of view there is a diffuse presence of extracellular and perivascular neuritic plaques and intracellular neurofibrillary tangles in the cerebral parenchyma of Alzheimer patients.

In addition to these histopathologic lesions, the primary neurotransmitter acetylcholine as well as other neurotransmitters such as serotonin, noradrenaline, dopamine, glutamate and substance P are degraded (Price DL *et al*, Ann NY Acad Sci 1985; 457: 35-51). Acetylcholinesterase inhibitors have been employed in an attempt to increase acetylcholine levels in the brain, but this pharmacological approach to the problem has yielded modest clinical results and has not had a significant impact on the natural history of the disorder (Davies P, *JAMA* 1999; 281: 1433-1434). For this reason in recent years research has focused its efforts on understanding the mechanism behind the formation of the characteristic lesions found in the brain of Alzheimer patients: neuritic plaques and neurofibrillary tangles.

Neuritic plaques are composed mainly of aggregates of a protein with 39-43 amino acid residues known as β-amyloid (Selkoe DJ, *J Neurochem* 1986; 46: 1820-1834). The β-amyloid protein is a derivative of a complex transmembrane glycoprotein (Kang J *et al*, *Nature* 1987; 325: 733-736) known as amyloid precursor protein (APP), and comprises a small part of the extracellular domain. The initial step of the metabolic pathway of APP involves the α-secretase enzyme that cleaves out APP within the β-amyloid sequence (Esch FS *et al*, *Science* 1990; 248: 1122-1124) allowing for the release of its transmembrane fragment. This metabolic pathway is not amyloidogenic because it precludes the formation of β-amyloid and leads to the release of APPα that appears to exert neuroprotective activity (Mattson MP *et al*, *Neuron* 1993; 10: 243-254). The metabolic pathway, defined amyloidogenic, that leads to the formation of β-amyloid is due to the enzyme β-secretase that releases APPβ plus a 12 kDa protein fragment, which in turn

is cleaved by the γ- secretase enzyme (Esler WP *et al*, *Science* 2001; 293:1449-1454) giving way to soluble Aβ.

Mutations of APP and of other recently identified proteins such as presinilins (PS-1 and PS-2), associated with familial forms of early onset Alzheimer, result in an overproduction of β-amyloid, or at least of its 42 amino acid form (Sherrington R *et al*, *Nature* 1995; 375: 754-760, Rogaev EI *et al*, *Nature* 1995; 376: 775-778). In addition, several studies have shown that the overproduction of β-amyloid may be promoted in the presence of apolipoprotein E type 4 allele, a known risk factor implicated in Alzheimer's disease. . These data seem to indicate that genetic changes commonly associated with Alzheimer's disease are involved in the increased production of β-amyloid protein.

There are several variants of the β-amyloid protein, derived by proteolytic cleavage from APP, that differ only in terms of the C-terminal domain: $A\beta_{39}$, $A\beta_{40}$, $A\beta_{42}$ and $A\beta_{43}$. The 40 and 42 aminoacid forms are found predominantly in the extracellular neuritic plaques, while the 39 residue peptide is the predominant component found in cerebrovascular deposits (Mori H *et al*, *J Biol Chem* 1992; 267: 17082-17086, Prelli F *et al*, *Biochem Biophys Res Commun* 1988; 151: 1150-1155). The amino acid sequence (primary structure), characterized by the presence of some hydrophobic amino acids, is such that the amyloid protein may take on both an α-helical and β-sheet conformation. Even though the two structures are approximately isoenergetic in the diagram of Ramanchandran, the protein adopts the β-sheet conformation in Alzheimer's disease for reasons not yet clear. Contrary to the α-helix form that is soluble in the cerebral parenchyma, the β-sheet form gives origin to the neurotoxic aggregates of the protein. β-amyloid fibrils are believed to be formed by two β-sheet filaments, derived from protein folding, and linked by an α-helix turn (Soto C *et al*, *J Neurochem* 1994; 63: 1191-

1198). The deposition of β-amyloid aggregates is thus highly correlated with its secondary β-sheet structure (Soto C *et al*, *Neurosci Lett* 1995; 200: 105-108). The fibrillogenesis of the β-amyloid protein involves a two-stage polymerization process: an initial "nucleation" process followed by "polymer elongation" that gives origin to the protofibrils (Jarrett JC *et al*, *Cell* 1993; 73: 1055-1058). The alignment of the protofibrils generates the β-amyloid fibrils.

The correlation among histopathologic lesions, brain cell death and cognitive deficiency in Alzheimer's disease is the basis of different etiology theories for the pathogenesis of Alzheimer's disease. The amyloid theory sustains that β-amyloid deposits in the brain of Alzheimer patients cause the disorder. Important evidence sustains this theory: (i) autopsies performed on the brain of Alzheimer patients consistently reveal β-amyloid deposits (McKhann G *et al*, *Neurology* 1984; 34: 939-944); (ii) all of the dominating autosomic mutations associated with the familial early onset forms of Alzheimer's disease are characterized by an overproduction of β-amyloid 1-42 (Citron M *et al*, *Nature* 1992; 360: 672-674, Scheuner D *et al*, *Nat Med* 1996; 2: 864-870, Suzuki N *et al*, *Science* 1994; 264: 1336-1340, Citron M *et al*, *Nat Med* 1997; 3: 67-72, Borchelt DR *et al*, *Neuron* 1996; 17: 1005-1013); (iii) the formation of β-amyloid plaques precedes the symptoms of the disease (Lippa CF *et al*, *Lancet* 1998; 352: 1117-1118). (4) The clearance of β-amyloid1-42 in the brain of patients appears to be reduced (Motter R *et al*, *Ann Neurol* 1995; 38: 643-648).

An important step in the research of Alzheimer's disease was the development and use of transgenic mice carrying one or more familial mutations of APP (Hsiao K *et al*, *Science* 1996; 274: 99-102, Games D *et al*, *Nature* 1995; 373: 523-527, Lamb BT *et al*, *Hum Mol Genet* 1997; 6: 1535-1541, Mucke L *et al*, *Ann N Y Acad Sci* 1996; 777: 82-88). The overproduction of APP, the extent of β-amyloid deposits in the brain, neuritic

dystrophy, and synapse loss observed in this animal model was of the same order as that observed in patients with Alzheimer's disease. There has been a recent report of a transgenic mouse with nerve growth factor (NGF) antibodies showing cortical and hippocampal accumulations of both β-amyloid protein and τ hyperphosphorylate protein (Ruberti F *et al*, *J Neurosci* 2000; 20: 2589-2601). The aged anti-NGF transgenic animals showed an extensive neuronal loss in the cortex, cholinergic deficiency in the nucleus basalis and cognitive and behavioral deficiency (Capsoni G *et al*, *Proc Natl Acad Sci USA* 2000; 97: 6826-6831). These animals are extremely useful in testing new therapeutic theories that could modify the natural history of the disorder.

Currently several therapeutic approaches are being developed based on the amyloid theory of Alzheimer's disease. One of these is related to identifying selective γ-secretase (Wolfe MS *et al*, *J Med Chem* 1998; 41: 6-9, Higaki J *et al*, *Neuron* 1995; 14: 651-659) or β-secretase (Sinha S *et al*, *Proc Natl Acad Sci USA* 1999; 96: 11049-11053) inhibitors that could block the formation of β-amyloid protein and reduce amyloid plaques, thus decreasing brain cell dysfunction and death. Another approach involves the inhibition of β-amyloid aggregates with products that modify the secondary structure of the protein or that bind to specific regions of the protein itself (Soto C *et al*, *Nat Med* 1998; 4: 822-826, Poduslo JF *et al*, *J Neurobiol* 1999; 39: 371-382, Biochemistry 1999; 38: 6791-6800).

Recently, the Athena Neuroscience international patent application WO 99/27944, claimed the same β-amyloid protein or its active fragment, as an agent able to induce an immunogenic response to β-amyloid, in the prophylaxis and treatment of amyloidogenic disorders and in Alzheimer's disease in particular. Schenk *et al.* have demonstrated that immunization using β-amyloid1-42 in transgenic mice harboring a mutant version of APP (PDAPP) inhibits the formation of amyloid plaques and histopathologic

lesions (Schenk D *et al*, *Nature* 1999; 400: 173-177). The immunization of young animals results in the almost total absence of β-amyloid deposits in old age with a significant inhibition of neuritic dystrophy (a marker of neuronal dysfunction) and of astrogliosis (a marker of cerebral inflammation). The immunization of aged animals (11-12 months) that had already developed β-amyloid plaques prevented additional histopathologic lesions and even led to their partial regression. The residual amyloid plaques are actively metabolized by microglia cells, suggesting that the immunization may, in addition to preventing the deposit of new amyloid, lead to the elimination of already existing deposits. The clearance effect of the β-amyloid protein is thought to take place through a mechanism of phagocytosis exerted by microglia monocytes. Other reports confirmed these initial findings (Janus C *et al*, *Nature* 2000; 408: 979-982, Morgan D *et al*, *Nature* 2000; 408: 982-985) thus supporting the idea of developing a protein β-amyloid1-42 vaccine for Alzheimer patients.

A further understanding is needed before some of these aspects may be applied to Alzheimer's disease (St George-Hyslop PH *et al*, *Nature* 1999; 400: 116-117). First of all it has been observed that in order to achieve the same effect as that observed in mice models, high concentrations of β-amyloid1-42 antibodies are necessary. Thus, the immune response induced by a vaccine may not be sufficient in man. In addition, contrary to mice models, the phenomenon of tolerance may occur in man, whereby the human immune system may be unable to react against a protein belonging to its own organism (β-amyloid 1-42). Further, it would be preferable to administer the antigen as a vaccine in the dissociated form and in such a way as that is able to maintain its secondary soluble structure: endogenous factors could indeed favor transconformation and/or denaturization processes that have a negative impact on the duration of the activity. Although in WO 99/27944, a generic

awareness is reported about the conformational changes in the immunogen that could affect the qualitative form of the response, in the examples (p.25, lines 27-30), the immune response in animal was tested by using the aggregated form of $A\beta_{42}$, i.e. a mixture of oligomers in which the monomeric units are held together by noncovalent bonds (p.12, lines 32-34). Upon injection, said aggregated form might give rise to larger agglomerates which could locally precipitate so being not able of eliciting their immunogenic activity. The deposit of such agglomerated could also give rise to granuloma and fastidious inflammations at the administration site.

Finally, it would be more advantageous to provide compositions containing the antigen able to induce a sufficient immune response in man without the use of an adjuvant and in particular without the use of the Freund's adjuvant. Although WO 99/27944 it is also generally directed to compositions free of Complete Freund's adjuvant and notwithstanding that, in the specification examples with alternative adjuvants are reported, (par. IX p. 66) the best results have been achieved with an immunization treatment envisioning first the use of emulsions containing $A\beta_{42}$ peptide (in the aggregated form) and the Complete Freund's adjuvant followed by the use of emulsions containing Incomplete Freund's Adjuvant (see Fig. 14). Antibody response against $A\beta_{42}$ peptide alone was negligible (see again Fig. 14). On the other hand, the complete Freund's adjuvant unfortunately exhibits a series of toxic effects, some of which are serious (Broderson JR, *Lab Anim Sci* 1989; 39: 400-405, Claassen E *et al*, *Res Immunol* 1992; 143: 478-483, Mancardi S *et al*, *Exp Cell Res* 1999; 246: 368-375, Andersen KE *et al*, *Contact Dermatitis* 1996; 35: 127-128, Haak T *et al*, *Clin Exp Rheumatol* 1996; 14: 633-641, Rabchevsky AG *et al*, *Brain Res* 1999; 832: 84-96). Some concerns exists about the use of the incomplete form as well; moreover, although it is better tolerated in man, it seems unable to increase the cellular immune

response (Jensen FC *et al*, *Adv Drug Deliv Rev* 1998; 32: 173-186).

In view of the problems outlined above, it would be highly advantageous to provide compositions free of adjuvant to be used in the treatment or prophylaxis of disorders associated with an accumulation of β-amyloid, such as Alzheimer's disease, containing as vaccine a form of dissociated Aβ protein or fragment thereof either able either to maintain the soluble secondary structure and to elicit a sufficient immune response in man.

Heat shock proteins (Hsp), also known as stress proteins, were described for the first time in Drosophila as proteins that are released following heat shock. Later it was found that their release is also related to stress or traumas of other types (hypoxemia, chemical, etc.). Hsp are classified according to at least four categories based on size: Hsp90 (90 kDa), Hsp70 (70 kDa), Hsp60 (60 kDa) and small Hsp (< 20 kDa). Hsp act as an intracellular chaperone to proteins, facilitating the transition among different compartments, modifying the secondary and tertiary structure and assembly of multimers (Beckmann RP *et al*, *Science* 1990; 248: 850-854). Recently, an important humoral and cellular immunogenic role has also been attributed to Hsp (Mizzen L, *Biotherapy* 1998; 10: 173-189). Their strong immunostimulant properties have made them potentially significant therapeutic anti-infection and cancer agents. Hsp 90 and Hsp70 have recently been assessed as anti-cancer vaccines.

It has been demonstrated that the neurotoxicity of β-amyloid and τ hyperphosphorylate proteins induces an increase in Hsp, especially Hsp 70 in the brain of Alzheimer patients (Perez N *et al*, *Mol Brain Res* 1991; 11: 249-254, Johnson G *et al*, *Ann N Y Acad Sci* 1993; 695:194-197, Yoo BC *et al*, *J Neural Transm Suppl* 1999; 57: 315-322). It has also been shown that the expression levels of Hsp 27 increase in degenerative astrocytes in brain areas rich in senile plaques during the inflammatory process (Renkawek K *et al*,

Acta Neuropathol 1994; 87: 511-519).

In an attempt to increase the immune response of the antigen, fusion proteins (Ag-Hsp) deriving from a covalent bonding of an antigen protein (Ag) and a heat shock protein (Hsp) have recently been synthesized (Suzue K *et al, Proc Natl Acad USA* 1997; 94: 13146-13151). Contrary to protein antigens that activate the T helper CD4+ lymphocytes and generate a humoral immune response, these Ag-Hsp fusion proteins activate the T cytotoxic CD8+ lymphocytes, thus generating a cellular immune response (Huang O *et al, J Exp Med* 2000; 191: 403-408).

The role of Hsp in brain of patients with Alzheimer's disease has also been recently investigated (Yoo BC *et al J Neural Trasm* 1999; 57, 315-322).

OBJECT OF THE INVENTION

The compounds of the present invention are fusion proteins (Aβ-Hsp) (III) derived from the covalent bonding of protein β-amyloid or fragment thereof (Aβ) (I) and a heat shock protein (Hsp) (II). Fusion proteins Aβ-Hsp (III) exert immunization activity against the β-amyloid protein and are thus useful in the treatment of all pathologic conditions that are characterized by an overproduction of β-amyloid and by β-amyloid deposits, in particular in Alzheimer's disease.

$$\underset{(I)}{A\beta} \quad + \quad \underset{(II)}{Hsp} \quad \rightarrow \quad \underset{(III)}{A\beta\text{-}Hsp}$$

According to recent reports in literature (Schenk D *et al, Nature* 1999; 400: 173-177), the immunization achieved following the systemic administration of human ($A\beta_{42}$) β-amyloid protein (I) together with a suitable immune coadjuvant (Freund) to transgenic mice with a spontaneous accumulation of β-amyloid in the brain, prevents the deposition of β-amyloid in young animals and blocks additional deposition of the protein in aged animals who have already developed senile plaques. In addition to this

inhibitory effect exerted against β-amyloid deposition in the brain, histopathologic abnormalities (neuritic and astrogliosis dystrophy) are also attenuated.

The products (III), and the pharmaceutical preparations containing them, induce an immune response to the β-amyloid protein and inhibit and prevent neuropathologic symptoms induced by the aggregates of the protein, and as such, are useful in the treatment and in the prophylaxis of Alzheimer's disease. The specific heat shock protein that is bonded to the peptidic fraction of the β-amyloid protein may be appropriately modulated in order to stabilize the secondary and tertiary structure of the peptidic fragment of the β-amyloid protein, to increase the immunogenic potential and to favor cellular transition. As demonstrated in the following example, the fusion protein obtained by coupling $A\beta_{42}$ with Hsp70 is able to induce an immune response comparable to that of $A\beta_{42}$ in the presence of the Freund's adjuvant, suggesting that compositions containing said agents as vaccine could be used for inducing a therapeutic immune response in patients affected by Alzheimer's disease, without the need of an adjuvant.

There is no suggestion in the prior art for using heat shock proteins for enhancing the immune response of Aβ protein or fragments thereof in a so significant way to envision the possibility of using compositions free of adjuvants.

EP 526,511 proposes administration of homeopathic dosages (less than or equal to 10^{-2} mg/day) of Aβ to patients with pre-established Alzheimer's disease. In WO 99/27944, it is claimed, among others, that Aβ peptides can be linked to suitable carriers such as serum albumin, choleric toxin, immunoglobulin or attenuated diphtherotoxin CRM 197 (p. 20, lines 1-7) which may favor release and/or immune response; it is also generically stated that immunogenic peptides can also be expressed as fusion proteins with

carriers (p. 20, lines 33-36), but there no mention of heat shock proteins and, overall, there is no suggestion that the latter ones could be used for stabilizing the secondary structure of Aβand augmenting its immune response to the level which can be obtained in the presence of the Complete Freund's adjuvant.

Monomeric Aβ peptides expressed as fusion proteins are also the subject-matter of EP 641861 but even in this there is no mention of Hsp.

WO 94/29459 refers to the use of stress proteins for modulating the immune response. Among others, the invention is also directed to fusion protein comprising a stress protein fused to a protein against which an immune response is desired but fusion proteins between Aβ and Hsp are nor mentioned, neither the less exemplified.

The βA–fusion protein (III) can include any of the naturally occurring β-amyloid proteins or a peptidic fragments thereof, and any Hsp chosen among the heat shock proteins with a low (Hsp25, Hsp27, Hsp28, etc.) or those with a high molecular weight (Hsp60, Hp70, Hsp90, etc.).

Particularly preferred are the human forms of Aβ protein, i.e. $A\beta_{39}$, $A\beta_{40}$, $A\beta_{41}$, $A\beta_{42}$ and $A\beta_{43}$. Both the Aβ peptidic fragment and the heat shock protein can be appropriately chosen to obtain: i) the highest immunogenic response possible; improved tolerability; the most stable structure.

This invention also includes all the possible isomers of the compounds having the general formula (III) and their mixtures.

The present invention also includes the salts of those compounds having the general formula (III) that possess groups that can be salified, in particular the carboxylic and amino groups.

The physiologically tolerated salts are for example, in the case of molecules containing acid groups, salts of alkaline metals or alkaline-earth, such as sodium, potassium, lithium, calcium, magnesium, or salts formed with organic or amino acid amines, such as arginine. In the case of molecules

containing basic groups the salts can comprise inorganic acids, such as hydrochloric acid and sulfuric acid, and mono and dicarboxylic organic salts, such as acetic acid, tartaric acid and methansulfonic acid.

Although they do not belong to the preferred embodiment, the present invention also relates to preparations containing the fusion protein of general formula (III) and immune adjuvants such as that of Freund (complete or incomplete), Jung, Gerbu, QS-21.

A further embodiment of the invention concerns the nucleic acid sequence encoding the fusion protein .

The fusion proteins according to the invention can be prepared with the aid of appropriate recombinant vectors in host cells. The techniques of constructing vectors, transforming cells, bringing about expression of the fusion proteins in the transformed cells and isolating and purifying the expressed proteins are known *per se* to the person skilled in the art. Advantageously, the Aβ peptide can be linked to the heat shock protein by suitable linker amino acids.

Expression can take place not only in bacteria but also in a large number of host systems such as, for example, in mammalian, yeast and insect cells. The DNA constructs suitable for the various host cells are synthesized by known methods and incorporated in the genome of the host cells with appropriate control sequences in a conventional way.

Effective doses of the compositions of the present invention, for the treatment of the above described conditions vary depending upon many different factors, including means of administration, target site, physiological state of the patient, other medicament administered and whether treatment is prophylactic or therapeutic. The amount of fusion protein for administration can vary from 10 μg to 20 mg per injection, preferably from 100 μg to 10 mg.

A typical regimen consists of an immunization (priming induction)

followed by booster injections at suitable intervals.

The fusion proteins of the invention can be administered by any route for prophylactic and/or therapeutic treatment. The most typical route of administration are subcutaneous and intramuscular injections.

The pharmaceutical compositions containing the fusion proteins of the invention can also include a variety of other pharmaceutically acceptable components depending on the intended mode of administration.

The following examples illustrate in detail the invention.

Example 1

PREPARATION OF THE TEST MATERIALS, NAMELY THE FUSION PROTEIN Aβ_{42}-HSP70 AND THE Aβ_{42} PEPTIDE

Materials and Methods

Expression Vector Constructs

The DNA fragment containing the *Mycobaterium tuberculosis* Hsp70 sequence was synthesized by PCR technique using the genomic DNA extracted from the *M. tuberculosis* HR37Rv strain as template. The upstream primer overlapping the AUG start codon (Hsp70-up) contains the *BamHI* and *NcoI* sites, while the downstream primer overlapping the UGA stop codon (Hsp70-dw) contains the *XhoI* site. The amplified DNA was then digested with the *BamHI* and *XhoI* enzymes and cloned in a pGEM11 Z(f+) (Promega). A positive clone (p11[Hsp70]) was isolated and fully sequenced. The DNA fragment encoding for the *Homo sapiens* amyloid beta peptide 1-42 (Aβ_{42}) was synthesised by the annealing of the oligos Beta-1 and Beta-2. The Beta1/2 double strand DNA fragment contains: the *HindIII* site in the 5'of the untraslated sequence, the *NdeI* site that overlap the AUG start codon and the *BamHI* site coding for the linking aminoacids (Gly-Ser) between the Aβ_{42} and the Hsp70 sequence. The Beta1/2 DNA fragment was digested with *HindIII* and *BamHI* enzymes, and then cloned in the p11[Hsp70] vector. A positive

clone (p11[Aβ_{42}–Hsp70]) was isolated and fully sequenced. The p11[Aβ_{42}–Hsp70] was digested with the enzymes NdeI and XhoI, and the 2 Kb band coding for the chimeric protein Aβ–Hsp70 was then cloned in the pET24a plasmid (Novagen). A positive clone (p24[Aβ_{42}–Hsp70]) was isolated and fully sequenced.

Protein Purification

The *Escherichia coli* BL21/DE3 strain was transformed with the p24[Aβ–Hsp70] vector expressing the chimera Aβ_{42}–Hsp70 and with the pET24a as control. Overnight cultures of the transformants were diluted 1/100 in LB medium containing 30μg/ml of Kanamycin. The cultures were grown to an OD_{600nm} of 1 and recombinant protein production was induced by addition to the cultures of isopropylthiogalactoside (IPTG) at the final concentration of 1 mM, for a total of four hours. The Aβ_{42}–Hsp70 protein formed inclusion bodies and was then purified as follows. The cells were harvested by centrifugation at 10,000 rpm in a JA10 Beckman rotor. The cell pellet was resuspended in lysis buffer A and incubated at 30°C for 15'. Then an equal volume of lysis buffer B was added and incubated at 37°C for 15'. The cells were sonicated and then pelleted at 12,000 rpm in a JA17 Beckman rotor at 4°C for 15'. The pellet were resuspended and pelleted three times with the buffer C, D and E, respectively. The final pellet was resuspended in buffer F and then centrifuged as previously described the supernatant were frozen at -20°C. Proteins were refolded by dilution 1:100 in the refolding buffer for 16 hours at 4°C in agitation. The refolded solution was filtered with Millipore 0,45 μm filters and then it was concentrated of 20 fold by ultra-filtration with a Pellicon XL Cellulose 10K (Millipore) using a Labscale apparatus (operative pressures P_{in} = 20-30 Psi; P_{out}= 12-15 Psi) (Millipore).

The ultra-filtered solution was buffer exchanged using a G25 HiPrep 26/10 column (Amersham Pharmacia Biotech) using the buffer G, the protein

fraction was used for the ATP affinity chromatography. A column of ATP-agarose (Sigma) was equilibrated in buffer G plus 0.2% TritonX100 and 100 mM NaCl. Protein was loaded on the ATP column and subsequently the column was rinsed with: buffer G plus 0.2% Triton X100 and 600 mM NaCl; buffer G plus 100 mM NaCl; buffer G plus 100 mM NaCl and 5 mM ATP. The protein $A\beta_{42}$–Hsp70 was eluted with buffer G plus 100 mM NaCl and 25 mM ATP. $A\beta_{42}$–Hsp70 protein was polished by gel filtration using a HiLoad 16/60 Superdex 200 prep grade column (Amersham Pharmacia Biotech), the fractions containing the $A\beta_{42}$–Hsp70 protein were pooled and dialyzed against PBS and.then stored at –80°C.

Lysis buffer A: 50 mM Tris-HCl, pH = 8; 25 % sucrose; 1 mM EDTA, pH = 8; 0,1% NaN_3; 10 mM DTT; 5 mM $MgCl_2$; 0.5 mg/ml Lysozyme (SIGMA); 0.4u/ml DNAsi (EPICENTRE).

Lysis buffer B: 50 mM Tris-HCl, pH = 8; 1 % Triton X100; 100 mM NaCl; 0,1% NaN_3; 10 mM DTT;1 mM PMSF.

Buffer C: 50 mM Tris-HCl, pH = 8; 0.5 % Triton X100; 100 mM NaCl; 1 mM EDTA, 0,1% NaN_3; 1 mM DTT.

Buffer D: 50 mM Tris-HCl, 1 M NaCl.

Buffer E: 50 mM Tris-HCl, 1 M urea.

Buffer F: 50 mMTris-HCl pH=8, 7M urea.

Buffer G: 100 mM Tris-HCl pH = 7.5; 4 mM $MgCl_2$.

Refolding buffer: 500 mM L-Arginina:105.335 g/litro; 100 mM Tris-HCl pH = 8; 2 mM EDTA; 10mM L-Cysteine; 0.5 mM L-Cystine.

Results

The production of the chimeric protein $A\beta_{42}$-Hsp70 obtained from the fusion between the human amyloid beta peptide 1-42 ($A\beta_{42}$) and the *Mycobaterium tuberculosis* Hsp70 protein was achieved.

The synthetic nucleotide sequence of the $A\beta_{42}$ peptide was fused with

Hsp70 gene of the *M. tuberculosis* (Figure 1) and then cloned into the pET24a vector. This vector allows the expression of high levels of recombinant protein using the T7 expression system (Studier FW *et al*, *Methods Enzymol* 1990, 185: 60-89). The $A\beta_{42}$-Hsp70 fusion protein was found to be expressed at very high levels in E. *coli* (Figure 2). The $A\beta_{42}$-Hsp70 protein was purified as inclusion bodies and subsequently refolded. The protein was further purified by ATP affinity chromatography and gel filtration using a Superdex 200 prep grade column. The purity of the recombinant protein was assessed by SDS-PAGE (Figure 2): lanes 1, 2, 3 are cell lysates of the BL21/DE3 cells transformed with the empty vector, p24[$A\beta_{42}$Hsp70] prior to IPTG induction and after 4 hours of induction, respectively. Lane 4 represents the refolding of the $A\beta_{42}$Hsp70 protein, and lane 5 the purified $A\beta_{42}$Hsp70 protein (indicated by the arrow). (Visualisation by Coomassie staining).

Oligonucleotides Table

Hsp70-up	GGG ATC CAT GGC TCG [illegible] G[illegible]T C
HSP70-dw	CCG CTC GAG TCA CTT [illegible] C[illegible]C CCG
BETA-1	CCC AAG CTT CCA TAT GGA TGC AGA ATT CCG ACA TGA CTC AGG ATA TGA AGT TCA TCA TCA AAA ATT GGT GTT CTT TGC AGA AGA TGT GGG TTC AAA CAA AGG TGC AAT CAT TGG ACT CAT GGT GGG CGG TGT TGT CAT AGC GGG ATC CAT GGC TC
Beta-2	GAG CCA TGG ATC CCG CTA TGA CAA CAC CGC CCA CCA TGA GTC CAA TGA TTG CAC CTT TGT TTG AAC CCA CAT CTT CTG CAA AGA ACA CCA ATT TTT GAT GAT GAA CTT CAT ATC CTG AGT CAT GTC GGA ATT CTG CAT CCA TAT GGA AGC TTG GG

Example 2

EVALUATION OF SYSTEMIC IMMUNE RESPONSES TO THE FUSION PROTEIN $A\beta_{42}$-HSP70

Material and Methods

Test Materials

β-amyloid1-42 peptide ($A\beta_{42}$) was bought from Unipeptides Inc. (Riverside, CA). The $A\beta_{42}$-Hsp70 fusion protein was prepared according to the Example 1.

Animal Care

All animal experimentation were conducted in accordance to the current European guide lines for the use of animals in *in vivo* experimentation. The animals were housed under controlled conditions in group of ten per cage. On arrival to laboratory, each animal was assigned an identifying code. Periodic examinations of health were performed using microbiological, parasitological and serological techniques aimed at identifying undesirable and pathogenic organisms.

Preparation of Test Materials

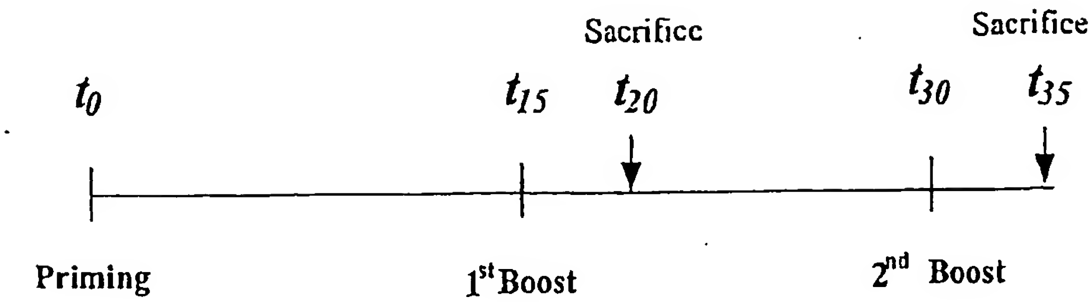
The test materials were used as lyophilised powders. Each test material was suspended at a concentration of 2 mg in 0.9 mL of sterile water, vortexed and added with 100 μL of 10 X phosphate buffered saline (PBS), where 1 X PBS is 0.15 M NaCl, 0.01 M sodium phosphate, pH 7.5. Suspensions were vortexed again and incubated overnight at 37°C for use the next day. Suspensions were prepared and codified by an independent operator in order to perform the study following a double blind procedure. Before administration, the $A\beta_{42}$ peptide was mixed with complete (*priming induction*) or incomplete (*subsequent challenges*) Freund's adjuvant in a ratio of 1:1 (v/v).

Animal Immunisation

The above processed test materials were administered subcutaneously at defined times (see below) to separate adult male mice (20-25 g, Balb/c, Charles-River, Lecco, Italy). Of noteworthy in this regard is that the choice of the administration route and animal species, is based on the fact that: a) the subcutaneous route of administration is widely used in immunisation studies as the presence of specialised antigen-presenting cells (e.g. macrophages and dendritic cells) in the subcutaneous district induce a strong immunologic response; b) the mouse is a widely used animal species for studies on induced immunological responses. In addition, all transgenic animal models of Alzheimer's disease currently available are in the mouse.

Mice were administered 10 or 100 μg of test material, according to the experimental scheme reported below. Each group was formed by 3-5 animals. Animals received, subcutaneously and in a dose corresponding to the assigned group, the $A\beta_{42}$ peptide mixed with complete Freund's adjuvant in a ratio of 1:1 (v/v) or alternatively the $A\beta_{42}$-Hsp70 fusion protein alone (*priming induction*). Fifteen and 30 days after priming, animals received the first and second boost, respectively. Each time they were injected subcutaneously with $A\beta_{42}$ peptide solution mixed with incomplete Freund's adjuvant in ratio of 1:1 (v/v) or with the $A\beta_{42}$-Hsp70 fusion protein solution (*subsequent challenges* following priming induction). Animals of each group were sacrificed, by cervical dislocation, 5 days after receiving boost, i.e. 20 and 35 days after priming with antigen. Blood was collected for assessment of humoral immune responses (see below).

Also of noteworthy is that the priming induction, subsequent challenges and specimens collection were performed by an operator who was not informed about the nature of the administered solutions.



Assays

Antibody formation was initially evaluated in the sera prepared from the collected blood samples by immuno-blot analyses. In the case of positive results, antibody titres in the sera of the different animals were assessed via ELISA methodology.

Results

The results in terms of anti-Aβ serum IgG antibody titres at day 20 and day 35 in mice injected on day 1, day 15 and day 30 with 10 μg of $A\beta_{42}$ peptide (2 nmoles) or 100 μg of $A\beta_{42}$-Hsp70 (1 nmole) fusion protein are plotted in Figure 3. Mice treated with $A\beta_{42}$ received complete Freund's adjuvant at day 1 and incomplete Freund's adjuvant at day 15 and day 30. Mice treated with the $A\beta_{42}$-Hsp70 fusion protein did not receive Freund's adjuvant. The average titre (± standard error) is shown. Titres were defined as the reciprocal of the dilution of serum giving one half the maximal optical density.

As it can be appreciated, the $A\beta_{42}$-Hsp70 fusion protein, obtained by coupling $A\beta_{42}$ with Hsp70, is able to induce an immune response comparable to that of $A\beta_{42}$ in the presence of the Freund's adjuvant, suggesting that compositions containing the fusion protein as vaccine could be used for inducing a therapeutic immune response in patients affected by Alzheimer's disease, without the need of an adjuvant.

CLAIMS

1. A fusion protein of the following formula:

$$A\beta\text{-}Hsp \qquad (III)$$

its relative isomers, salt mixtures, in which Aβ is a β-amyloid protein or a fragment thereof and Hsp is a protein belonging to the family of low or high molecular weight heat shock proteins.

2. A fusion protein according to claim 1 in which Aβ is selected from β-amyloid1-39, β-amyloid1-40, β-amyloid1-42.

3. A fusion protein according to claim 1 or 2 in which Hsp is selected from Hsp 25, Hsp 27, Hsp 28, Hsp 60, Hsp 70, Hsp 90.

4. A nucleic acid sequence encoding for a fusion protein according to claims 1-3.

5. A pharmaceutical preparation having as its active ingredient a fusion protein according to claims 1-3, in combination with diluents, and/or pharmacologically acceptable excipients and optionally an immune co-adjuvant.

6. A pharmaceutical preparation according to claim 5, in which the immune coadjuvant is selected from the Complete or Incomplete Freund's adjuvant, Jung, Gerbu and QS-21.

7. Use of a fusion protein- according to claims 1-3, in combination with diluents, pharmacologically acceptable excipients and optionally coadjuvants for the preparation of medicinal products in the treatment or prophylaxis of disorders associated with an abnormal production β-amyloid, in particular in Alzheimer's disease.

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271 K D K M A M Q R L R E A A E K A K I E L S S S Q S T S I N L

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661 E V V D D G R E A K *

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Figure 1. Nucleotide and the aminoacid sequences of the $A\beta_{42}$-Hsp70 protein. The $A\beta_{42}$ sequence (underlined), the linker aminoacid sequence (bold) and the Hsp70 protein sequence (remaining).

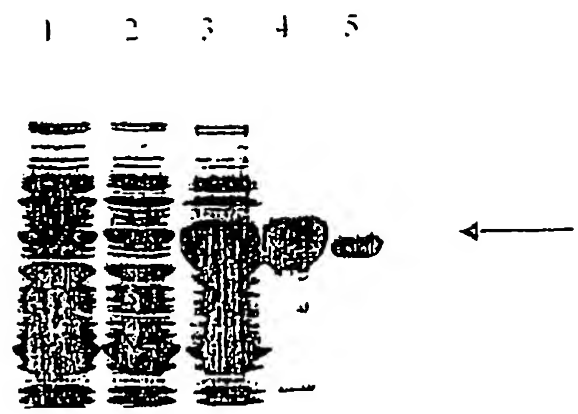

Figure 2. Production of recombinant protein. *E. coli* cell lysates and purified protein were analysed by SDS-PAGE and protein were visualised by Coomassie staining.

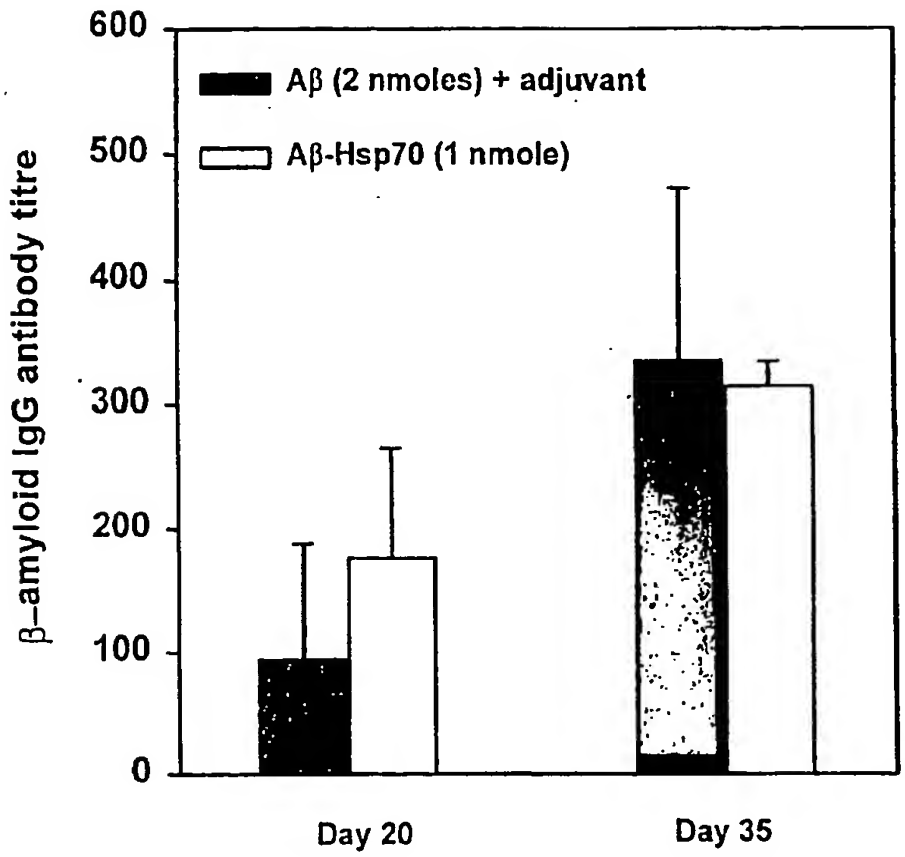

Figure 3. Anti-Aβ IgG antibody titre at day 20 and day 35 in mice injected on day 1, day 15 and day 30 with 2 nmoles of β-amyloid$_{1-42}$ (10 μg) or 1 nmole of Aβ-Hsp70 fusion protein (100 μg).

SEQUENCE LISTING

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<120> FUSION PROTEINS AS IMMUNIZATION TREATMENTS OF
ALZHEIMER'S DISEASE

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/12242

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C07K14/47 A61K39/385 A61P25/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, CHEM ABS Data, BIOSIS, MEDLINE, EMBASE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
P,X	WO 01 52890 A (UNIV CONNECTICUT HEALTH CT) 26 July 2001 (2001-07-26) the whole document ---	1-7
P,X	WO 01 52877 A (UNIV CONNECTICUT HEALTH CT) 26 July 2001 (2001-07-26) the whole document ---	1-7
E	WO 02 11669 A (ANTIGENICS LLC) 14 February 2002 (2002-02-14) the whole document ---	1-7
A	WO 94 29459 A (WHITEHEAD BIOMEDICAL INST) 22 December 1994 (1994-12-22) ---	
A	WO 95 31994 A (FRIDKIN MATITYAHU ;KONEN WAISMAN STEPHANIE (IL); COHEN IRUN R (IL)) 30 November 1995 (1995-11-30) ---	

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 March 2002	08/04/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Cervigni, S

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 01/12242

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	WO 99 42472 A (IGEN INT INC) 26 August 1999 (1999-08-26) -----	

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